Note on Certain Coloured Interference Bands and the Colours of Tempered Steel.

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(Received April 25, 1918.)

But few people can have failed to notice the equally spaced dark bands which are seen when parallel rows of palings are viewed from a passing train, and which appear to advance at the same speed as the observer.

The general explanation of such bands is obvious, depending, of course, on whether the uprights of the nearest row are in line with those of the more distant, or whether both are visible at the same time. In the first case less obstruction is offered to the passage of light from the background than in the latter, so that the brightest part of the band occurs when, in the line of sight, the uprights of the two rows coincide, and the darkest, when both series are in view at the same time.

In 1874 I examined, with some care, the production of this class of interference bands, and there is a good deal of Italian work on the same subject. If the interfering lines are equally spaced, and parallel to the intersection of the planes in which they lie, the bands are not uniformly spaced, but come closer together as the line of sight departs from the normal to the mean plane. If the lines are not parallel to intersection of the planes, the bands become hyperbolic; and if the surfaces containing the lines are curved, the bands may assume very complex forms. Of this the wood-grain-like figures seen when looking through two folds of muslin or gauze are an example.

If, keeping the eye stationary, the distance between the two folds is altered and the form of the bands is expressed in terms of the distance between them, it will be found the curves lie on a family of quasi-cylindrical surfaces, one within the other, of which surfaces the bands themselves may be considered as plane sections. Hence there is a real analogy between the interference patterns seen through the gauze curtains and the grain patterns of tangential sections of wood, where the annual rings also form quasi-cylindrical surfaces.

Instead of using two sheets of gauze, the single sheet may be placed on looking glass, and the interference observed between the sheet and its reflected image. While making some experiments of this sort in 1874, I noticed that in some cases the bands so produced were rather strongly coloured. I have mentioned this fact to many people, but it does not seem to be generally known, and though the explanation is very simple, it may be worth recording.

In fig. 1 let AB be the section of a grating of pitch a, composed of opaque lines of width b, with transparent interval of width c; and let these lines cover the surface of a glass plate of thickness T, the back of which is silvered. Let μ be the mean refractive index of the glass, and $\Delta\mu$ the difference between the refractive indices for red and violet.

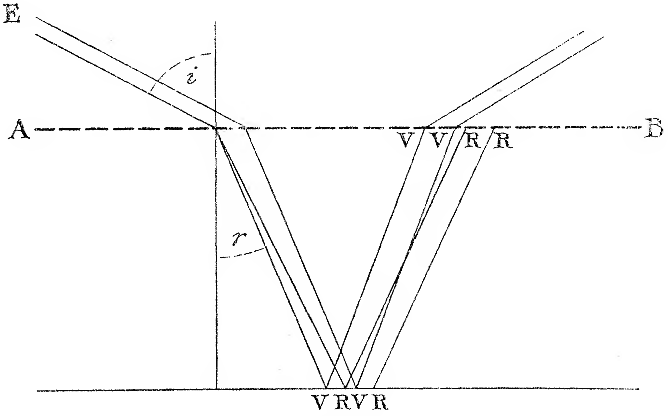

FIG. 1.

Let a beam of light fall on the grating at an angle of incidence i, and consider the course of the ray which passes the edge of one of the lines. The distance L_R between the red and violet rays at the point where, after reflection, they again meet the upper surface is $2T\Delta\mu \frac{\tan r}{\cos^2 r}$, or, in terms of i,

$$L_R = 2T\Delta\mu \frac{\sin i}{(\mu^2 - \sin^2 i)^{3/2}}.$$

Spectra of this length will be formed by the rays from every point in the width of c, and thus each aperture of the grating will produce a beam of width $L_R + c$ at the place of emergence, part of which will be stopped by one of the opaque lines. Hence the emergent light will be coloured. The purity of the colour in beam, before emergence, depends on the ratio c/T, but in any case the margins show pure spectrum colours. For the formation of the coloured interference bands now under consideration, c should be large compared to the wave-length (in order that diffraction effects may be small), and T should be large compared to c, to secure adequate separation of the colours.

If the grating is illuminated by diffused light and is observed from some point E, it will be seen that the combination of glass and grating is rather a crude form of Maxwell's colour box in which the slit used is wide, and the part of the spectrum which is suppressed is equal to the difference between the pitch of the grating and the width of the slit.

To estimate the colours which will be seen from E for different values of i, the method used by Maxwell and by Lord Rayleigh in his paper on the colours of these plates* is most convenient. The coloured strip formed by dispersion which contains all wave-lengths is to be replaced by three strips of primary violet, green, and red, each of width c, so disposed that their margins are coincident with the proper position which those colours would appear in spectrum formed by the glass by light passing the edge of b.

The quantity of each colour not prevented from reaching the eye by b is to be found, and the centre of gravity of weights proportional to these quantities placed at the angles of the chromatic triangle then indicates the colour which will be observed at E for a given value of i.

The primary colours used by Maxwell and Lord Rayleigh are:—

(1) A violet from between the G and F Frauenhofer lines,
(2) A green close to the E line, and
(3) A red near the C line.

A mixture of these in the proportions 30 V, 31 G, and 18 R gives white light.

In fig. 2 a part of the grating and primary colour strips are shown in plan.

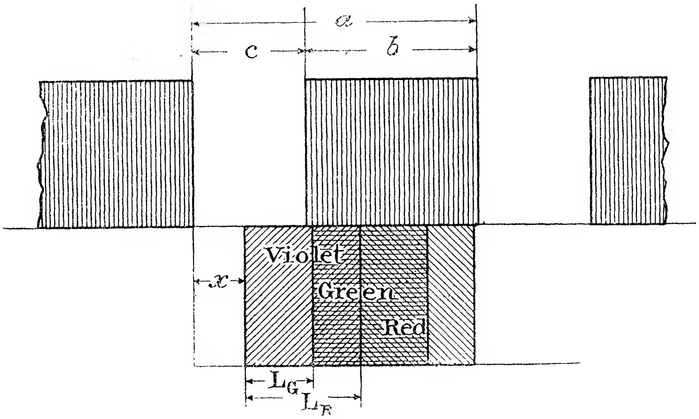

Fig. 2.

Let x be the distance of the left-hand margin of the violet from the right-hand edge of one of the opaque lines of the grating; L_G+x and L_R+x being the corresponding distances for the green and red.

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[*] See Lord Rayleigh, 'Collected Papers,' vol. 2, p. 498, *et seq.*

In passing from one interference band to the next, x will vary from 0 to a, and it is easy, from Diagram I, to write down the quantity of each colour which reaches the eye for any given value of x.

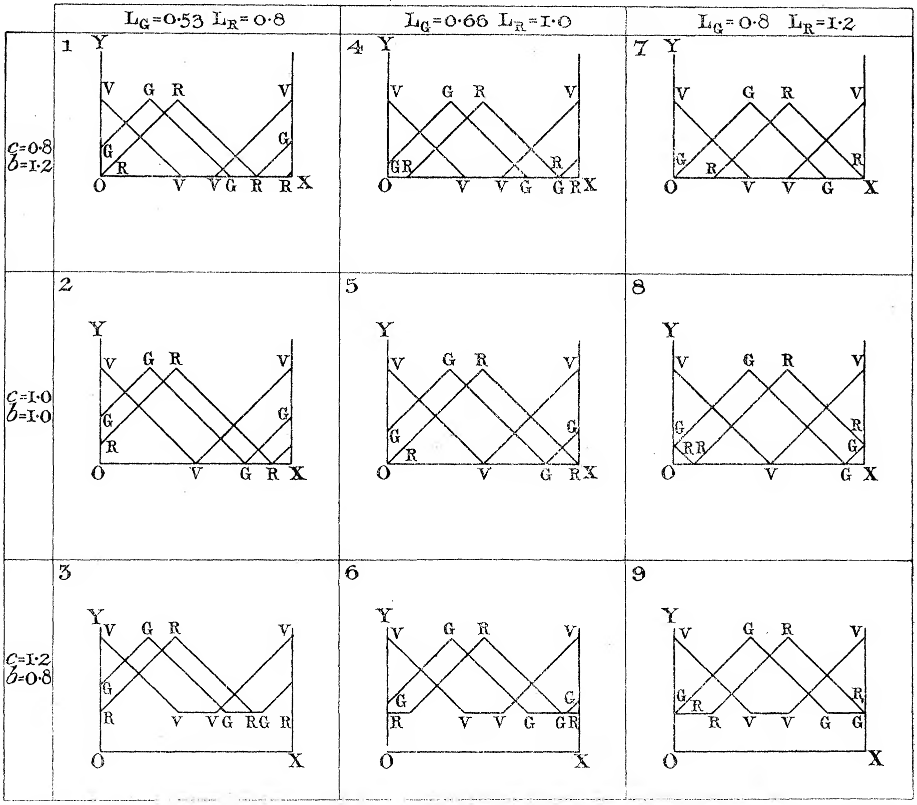

DIAGRAM I.—The ordinates (y) of the figures 1–9 represent the quantities of violet, green, and red, which reach the eye at E, in terms of the distance (x) between left-hand edge of the violet (see fig. 2) and the right-hand edge of the opaque part (b) of the grating. The values of b, c, L_G, and L_R, are given for each line and column of the diagram. As the angle of view (i in fig. 1) changes from the edge of one interference band to the corresponding point of the bands adjacent, x increases or diminishes from 0 to a or $-a$.

Diagram II gives the locus of the centres of gravity of these quantities in the colour triangle, while x varies through one complete cycle. The curves are curious and irregular, as might be expected from the discontinuity of the conditions which govern the mixture of the colours, but they all agree in one respect, namely that no green shows itself in any part of the band. In fact, green cannot appear in the resultant colour unless the dispersion, or thickness of the plate, is sufficient to separate the primary colour patches more or less completely from one another, and this agrees with observation.

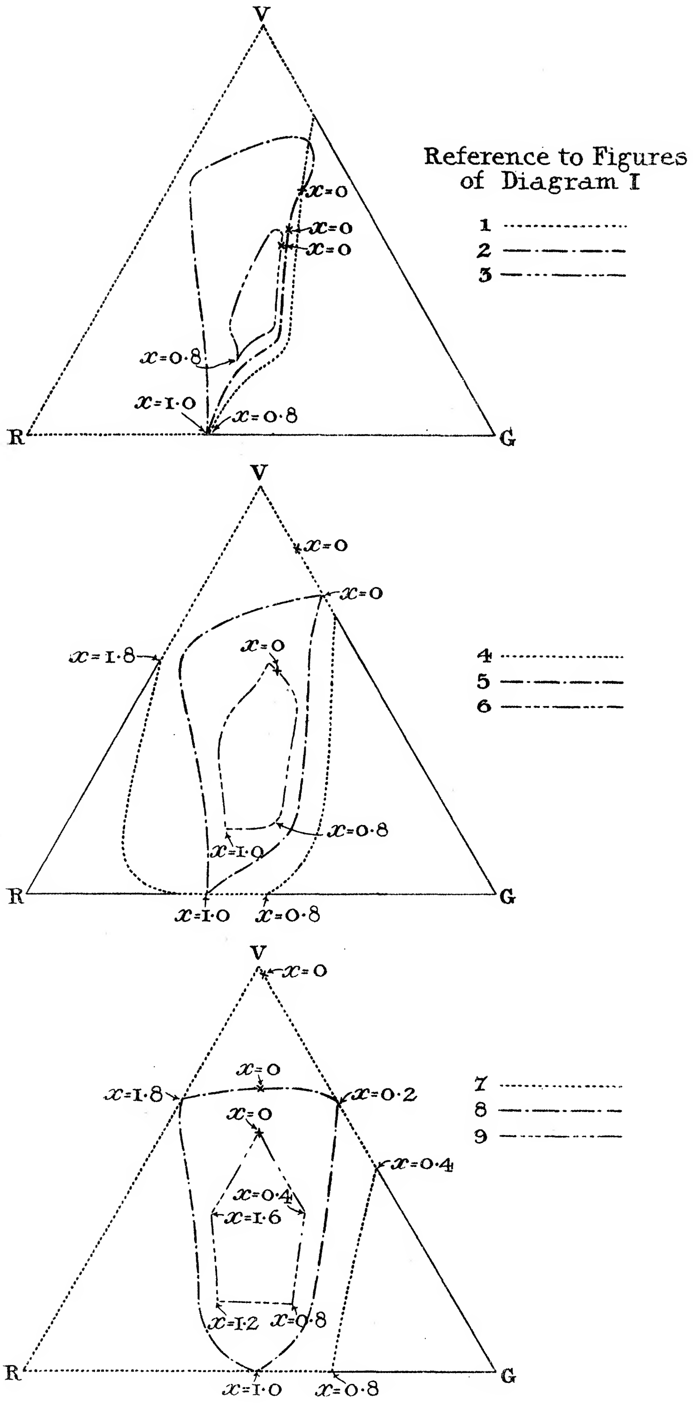

DIAGRAM II.—The curves within the chromatic triangles are the loci of the centres of gravity of weights proportional to the quantities of the primary colours reaching the eye, corresponding to the examples in Diagram II, whilst x varies from 0 to a. Values of x are written against the most marked features of the curves.

The actual colours in the cases figured range from good blues through reddish-purple and orange and a straw-yellow to nearly white. And in some instances the sequence is so close to the colours of tempered steel that I was led to examine the latter with some care.

I had always thought, and I believe it has generally been assumed, that the colours of tempering were instances of the ordinary interference colours of thin plates; but the following simple experiment seems to prove conclusively that this cannot be the true explanation.

If the colours were due to a film of appropriate thickness, a reduction of that thickness ought to change the colour; the blue should change to green, orange to yellow and so on. I found, however, that if the tempered steel surface was gently polished, until the clean surface of the metal was reached, there was no change of colour during the process, the blue remaining blue, and the yellow yellow, until the whole of the colour was removed. The intensity of the colour decreased as the film became thinner, but its character remained the same.

The colours of tempering are best seen by polarised light, and their intensity is greatest at the angle of maximum polarisation. When so observed the blue changes, as the angle of incidence increases, through reddish-purple to a dark orange and finally to a straw yellow. The yellow and orange parts, on the other hand, change but little, becoming rather more intense at the angle of maximum polarisation, but when the incidence is large, the whole surface which has been coloured by the tempering assumes a nearly uniform yellow.

Thus the blue moves towards the red end of the spectrum, while the orange does the opposite, and although similar changes occur in the case of the higher order of Newton's rings, the thickness of plate required is far greater than that which produced the colours of tempering. It would seem probable, therefore, that the latter colours are due to some form of selective opacity depending on damped molecular periods comparable with the wave period,* rather than on a structure comparable with the wave-length.

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* This must be true of all pigment colours, but something more is required to explain the dependence of the colours of tempering on the angle of incidence, a feature which is strongly marked also in the case of many of the aniline colours when examined as dry films by reflected light.